Economic Comparison of SO_3 Control Options for Coal-fired Power Plants

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Background

- Boilers firing bituminous coal convert ~0.5 to 1.5% of SO_2 to SO_3
- SCR retrofits, pet coke co-firing can double SO_3 formation
- Resulting sulfuric acid (H_2SO_4) and/or ammonium bisulfate (NH_4HSO_4) can cause problems:
  - SCR catalyst fouling
  - Air heater plugging or reduced plant efficiency
  - Back-end corrosion
  - Plume opacity

Background (continued)

- Existing emission controls do not collect SO_3/sulfuric acid at high efficiency:
  - 20% removal is typical across air heaters and cold-side ESPs
    - mostly adsorption, condensation
    - actual percentages vary
  - 50% removal is typical across wet scrubbers
    - measured range <10% to >80%

Example Sulfuric Acid Plume

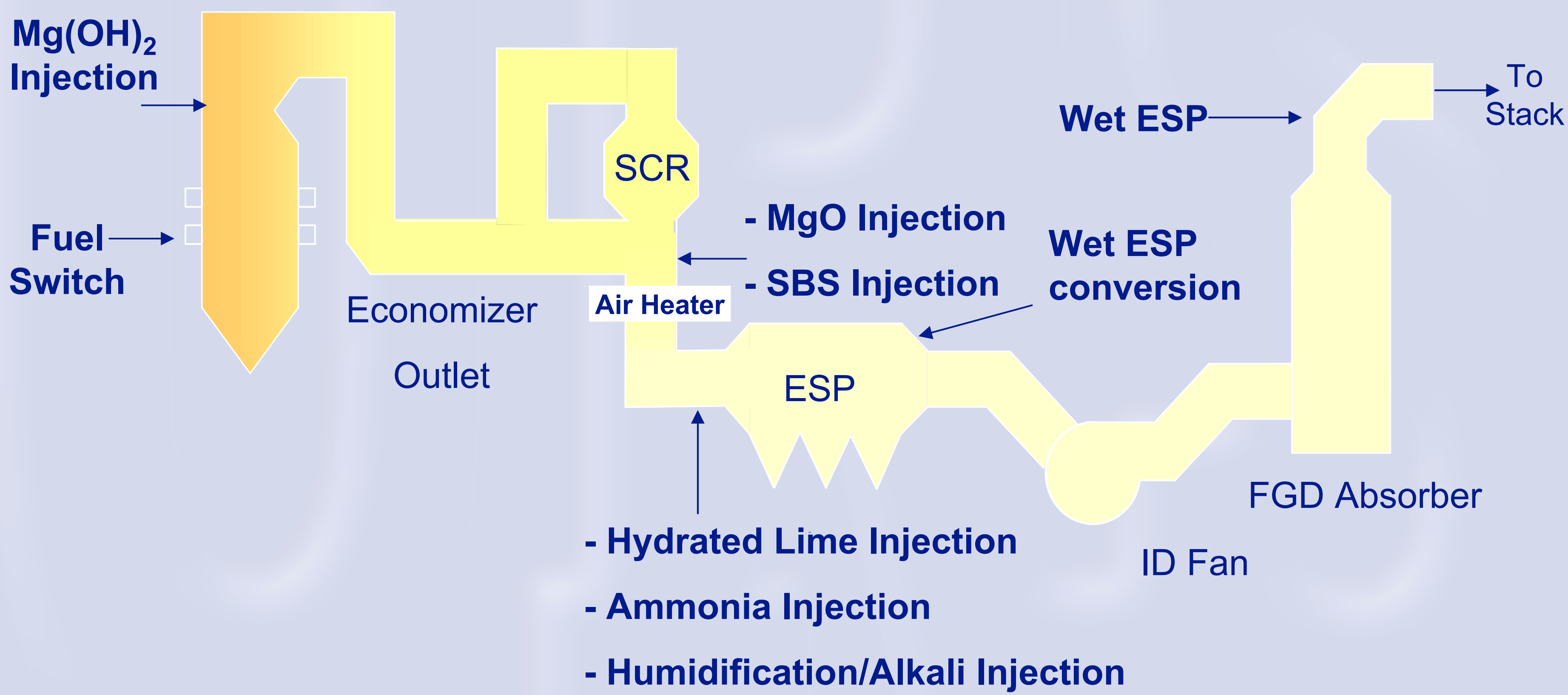
Note blue sulfuric acid plume

See “shadow” from opaque plume in the distance

Current DOE/EPRI/Utility Co-funded Project

- Investigated furnace injection of $Mg(OH)_2$ slurries (commercial and byproduct) for SO_3 control
  - Full-scale tests at FirstEnergy Bruce Mansfield Plant and AEP Gavin Station
  - Results presented at ‘01 and ‘03 Mega Symposia
- Economic evaluation (subject of this presentation) considered a wide range of potential SO_3 controls

Potential Sulfuric Acid Control Options



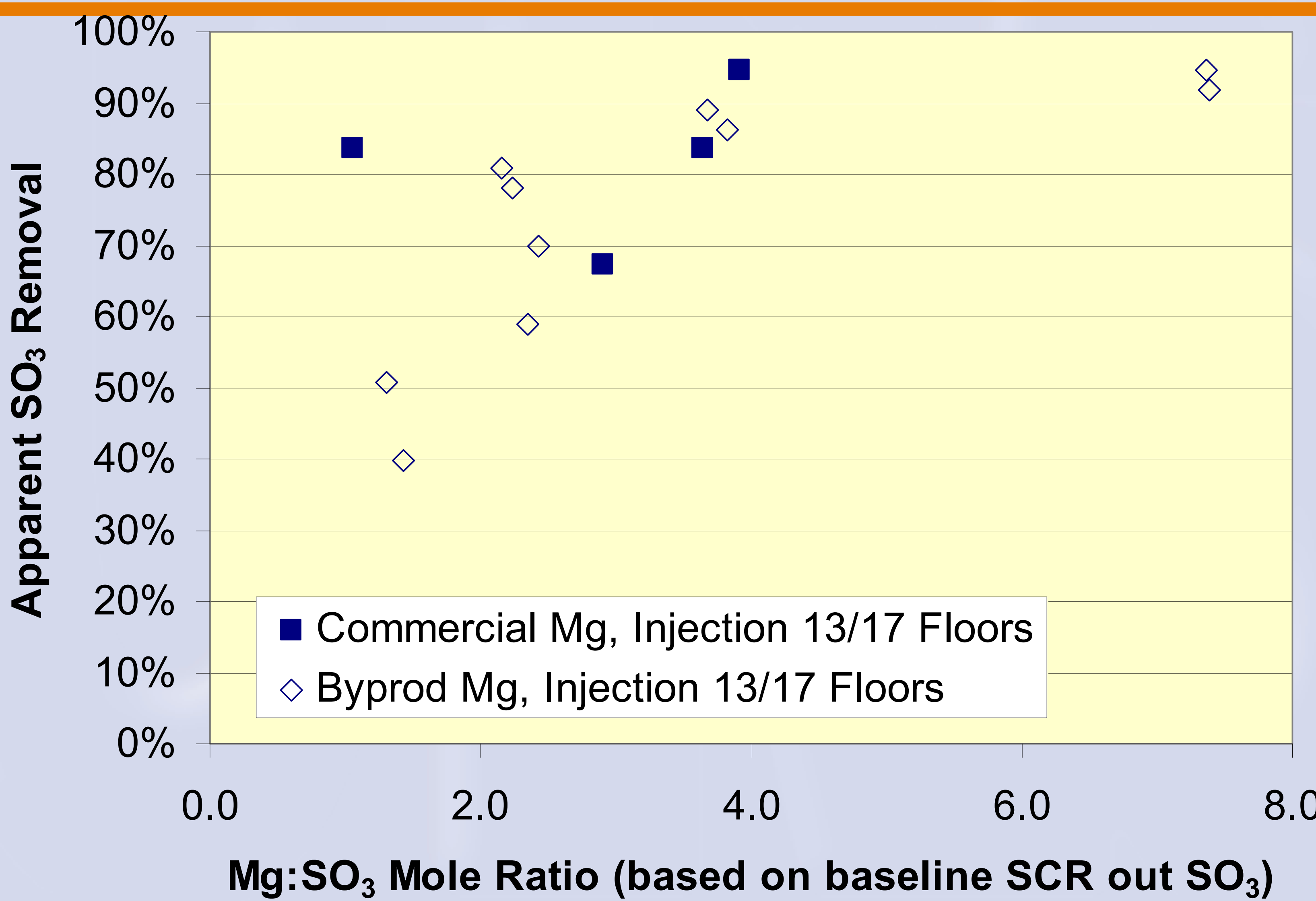
Fuel Blend/Switch (Low-sulfur Coal)

- Demonstrated for reducing SO_3 in flue gas and reducing plume opacity
- Potentially high operating cost, driven by fuel price differential
- Balance-of-plant issues need to be considered:
  - Coal yard
  - Mill capacity
  - Furnace fouling/slagging,
  - ESP performance, etc.

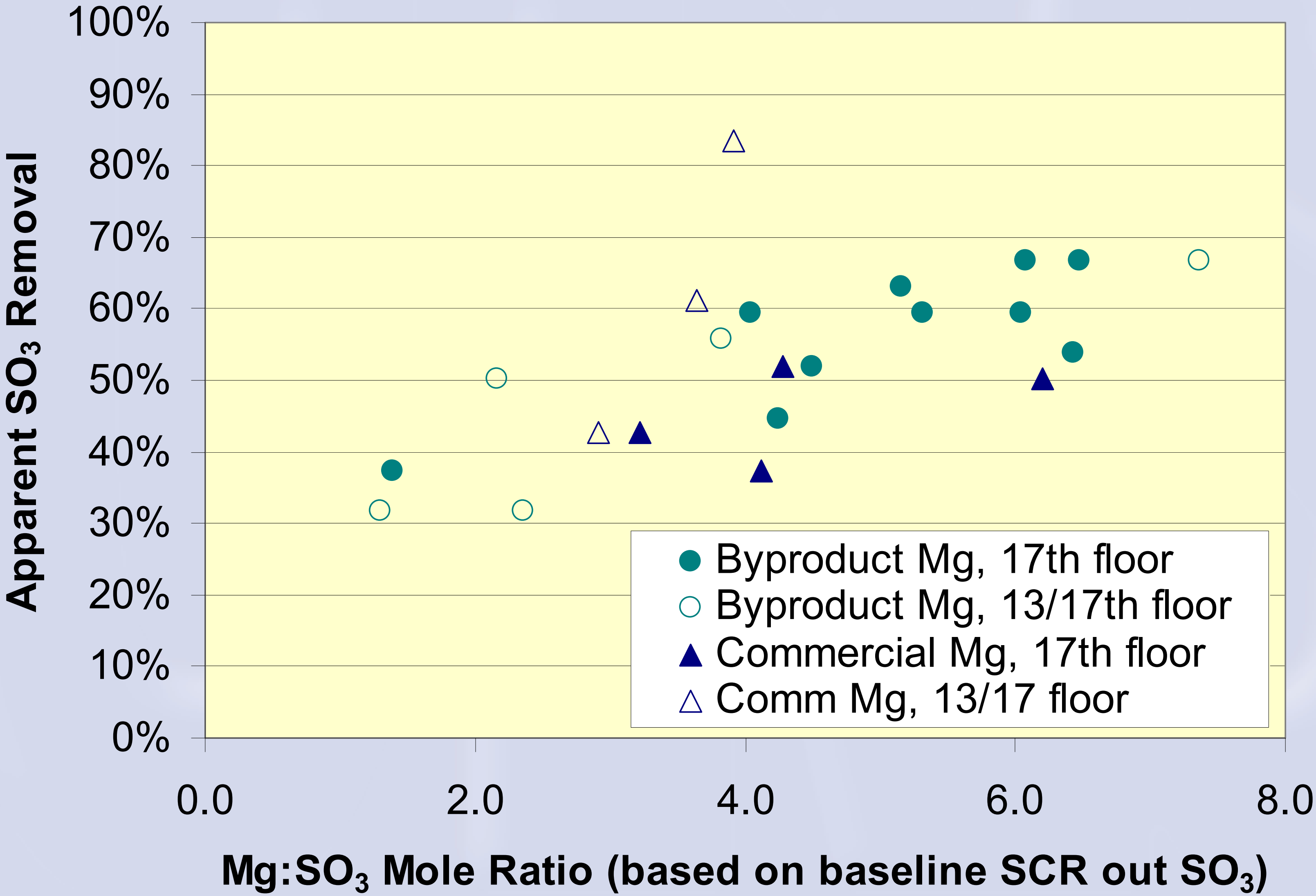
Furnace Injection of Mg Hydroxide Slurry

- Demonstrated in current DOE/EPRI project, but limited overall control effectiveness seen at AEP Gavin (with SCR)
  - High control percentage of furnace-formed SO_3
  - Little control of SCR-formed SO_3
- Potential benefits to SCR operation at low load
- Potential adverse effects on cold-side ESP at high control efficiency for plants without SCR

Gavin $Mg(OH)_2$ Injection Results - SO_3 Control at Economizer Outlet



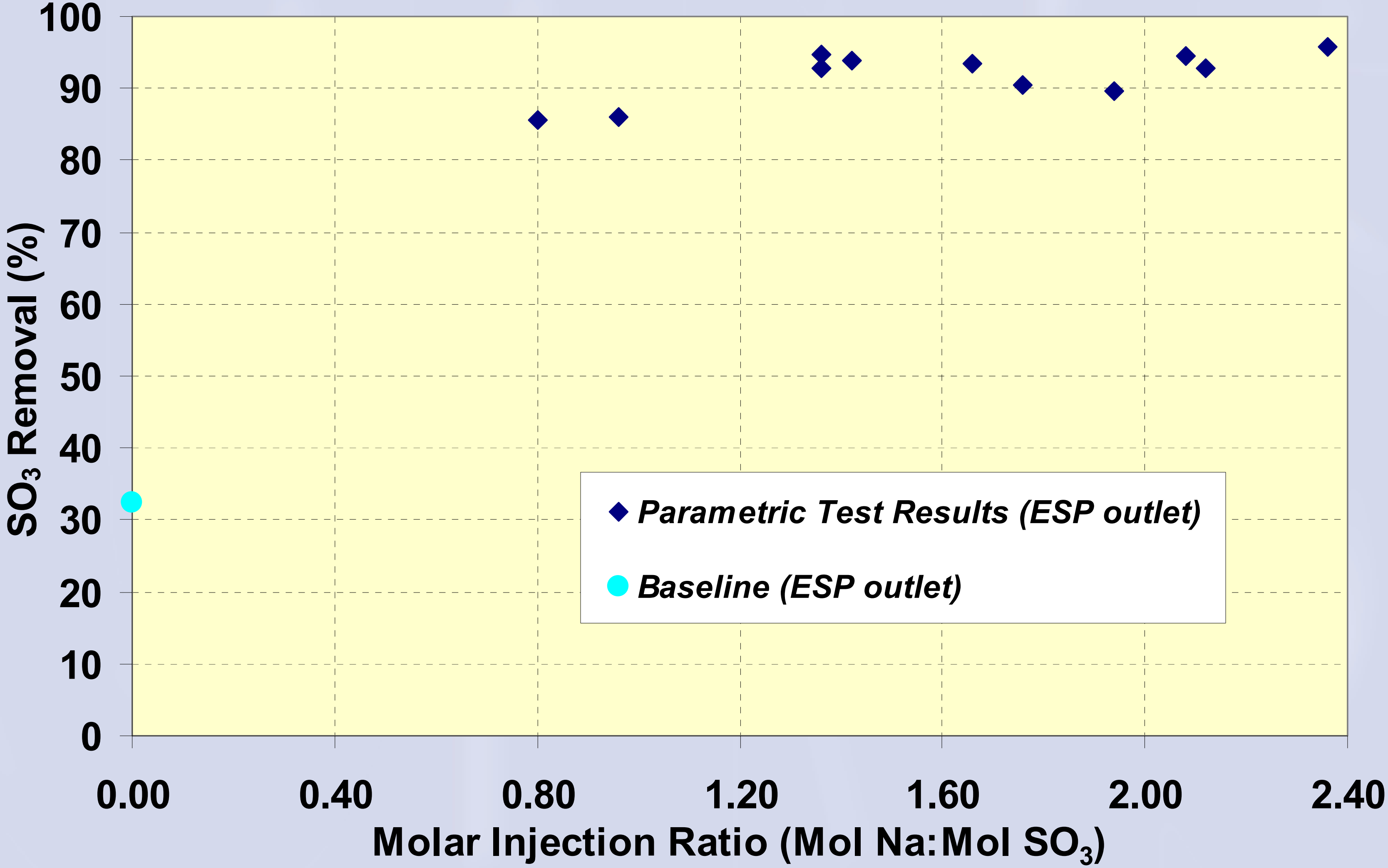
Gavin $Mg(OH)_2$ Injection Results - SO_3 Control at ESP Outlet

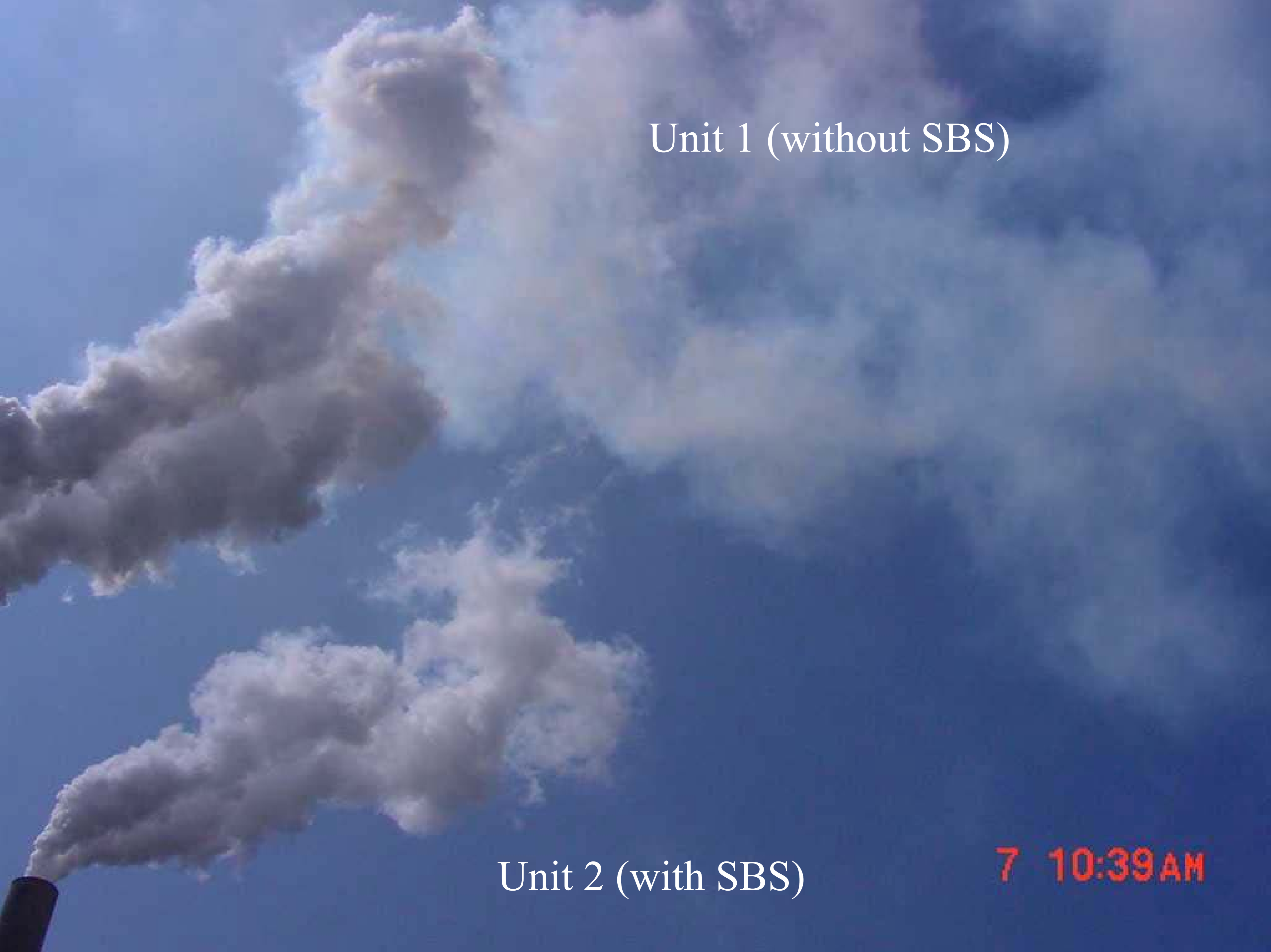


Injection of SBS Solution at SCR Outlet Duct

- Tested at five plants to date (two EPRI co-funded)
  - Medium to high S coal, with and w/o SCR
- Two commercial systems currently operating
- Can achieve high SO_3 removal percentages
- Concerns over:
  - Reagent cost
  - Reliability of injecting aqueous solutions in duct, impacts on air heater?

Vectren A.B. Brown Short-term SBS Results - ESP Outlet




Unit 1 (without SBS)
Unit 2 (with SBS)
7 10:39 AM

Injection of MgO Powder at SCR Outlet Duct

- Not well demonstrated
  - Only vendor data available
  - No performance data published for high SO_3 levels
- Could be cost effective if vendor data are proven
- Potential adverse effects on ESP at high control efficiencies

Alkali Injection Downstream of Air Heater

- **Ammonia Injection**
  - Low evaluated cost
  - Adverse effect on fly ash reuse
  - Other potential balance of plant impacts
- **Hydrated Lime Powder Injection**
  - Demonstrated at Gavin, EPRI pilot, others
  - Potentially high reagent costs
  - Adverse effects on ESP at high control percentages

Humidification/Lime Injection after Air Heater

- Demonstrated only at pilot scale (EPRI, upstream of ESP) or limited full-scale tests (Chemical Lime, upstream of FGD)
- Potential for duct corrosion, solids deposition
- Requires high particulate removal across scrubber if injected downstream of ESP
  - However, excess lime gets utilized as an FGD reagent
- Affects FGD water balance due to water sprayed in duct

Humidification Upstream of FGD Absorbers (no alkali injection)

- Not well demonstrated (one E.ON reference at low uncontrolled SO_3 levels)
- Potentially low cost (no new reagent)
- Requires high removal of condensed acid across scrubber
- Potential duct corrosion and FGD water balance issues
- Not included in this evaluation due to lack of performance data

Wet ESP – Conversion of Last Field of Existing Dry ESP

- Humidification in wet field condenses sulfuric acid in flue gas
  - Up to 60-80% SO_3 removal measured in EPRI pilot-scale tests
- Co-benefits from control of fine particulate and re-entrainment emissions
- Capital costs estimated at \$30 to \$40/kW
- No benefits to air heater
- Impacts FGD water balance
- Demonstrated at full scale only one site (Mirant Dickerson Station), no full-scale experience for high S coal, SCR, wet FGD combination

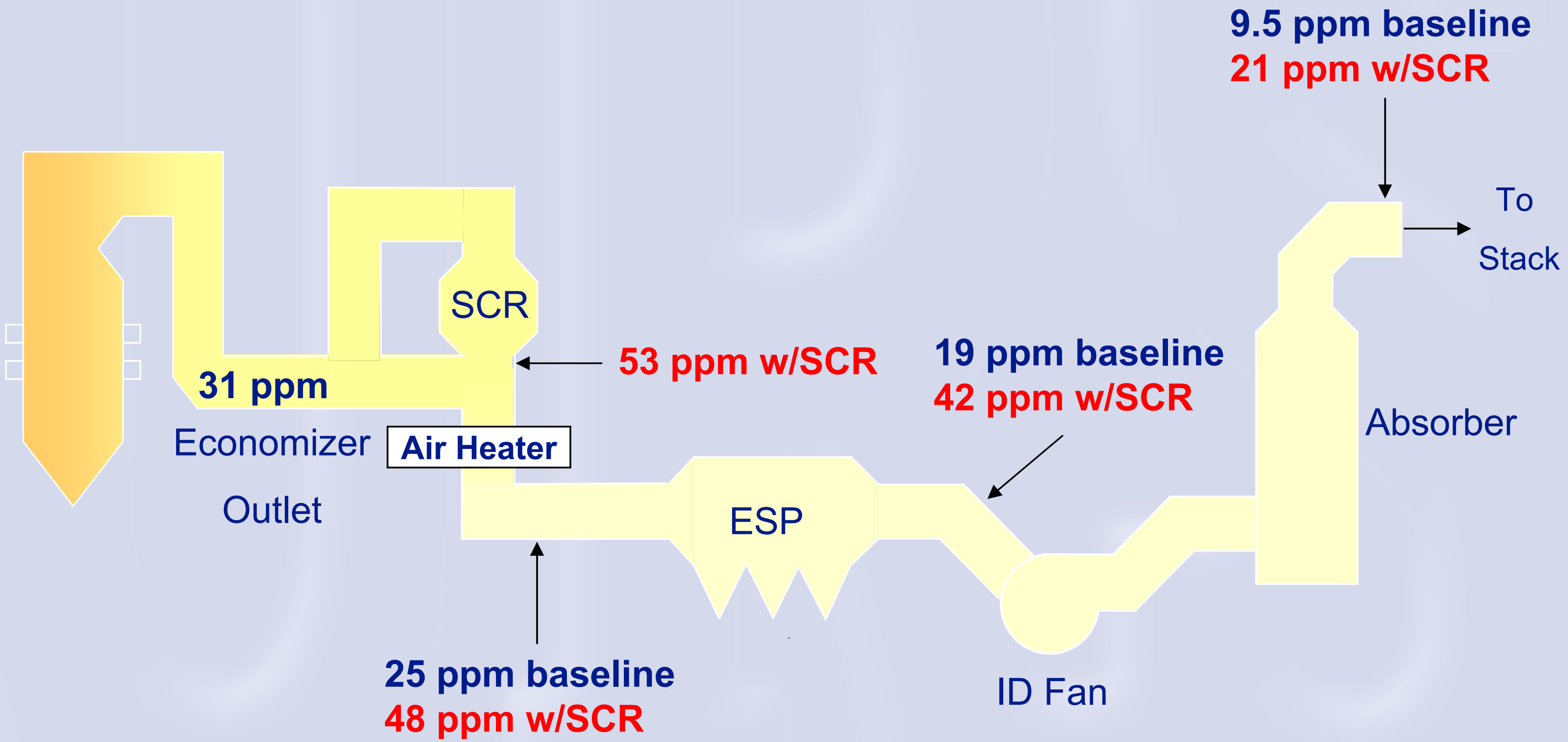
Wet ESP – Retrofit Downstream of Wet FGD

- Up to 95% or greater sulfuric acid removal
- Higher capital cost (~$40 to >$70/kW)
- Potentially long outage required to install
- No benefits to air heater or back-end corrosion
- Potential co-benefits from control of fine particulate emissions and/or stack rainout
- Demonstrated at full scale, but not for high S coal, SCR, wet FGD combination

Example SO_3 Control Economics

- Hypothetical plant (high S coal, SCR retrofit)
- Data from literature or current project used to estimate SO_3 control performance of technologies
- Material balance calculations used to estimate reagent and utilities consumption, size major equipment
- Capital cost estimates developed from factored estimates on major equipment purchase cost (except wet ESP, used \$/kW)

Example Plant SO_3 Concentrations - Before and After SCR Retrofit



Example Plant for Comparing SO_3 Control Technologies

Parameter	Value
Unit Load (gross MW)	500
Gross Plant Heat Rate (Btu/hr/KW)	9200
Capacity Factor (%)	85
Flue Gas Flow Rate (acfm at economizer outlet)	2.07×10^6
Coal Sulfur Content (%)	3.5
Flue Gas SO_2 Content (ppmv wet at economizer outlet)	2790
NO_x Season Duration (months/yr)	5
Target Stack Sulfuric Acid Concentration (ppmv, dry basis):	
For lower SO_3 removal percentage target	9.5
For higher SO_3 removal percentage target	3.0

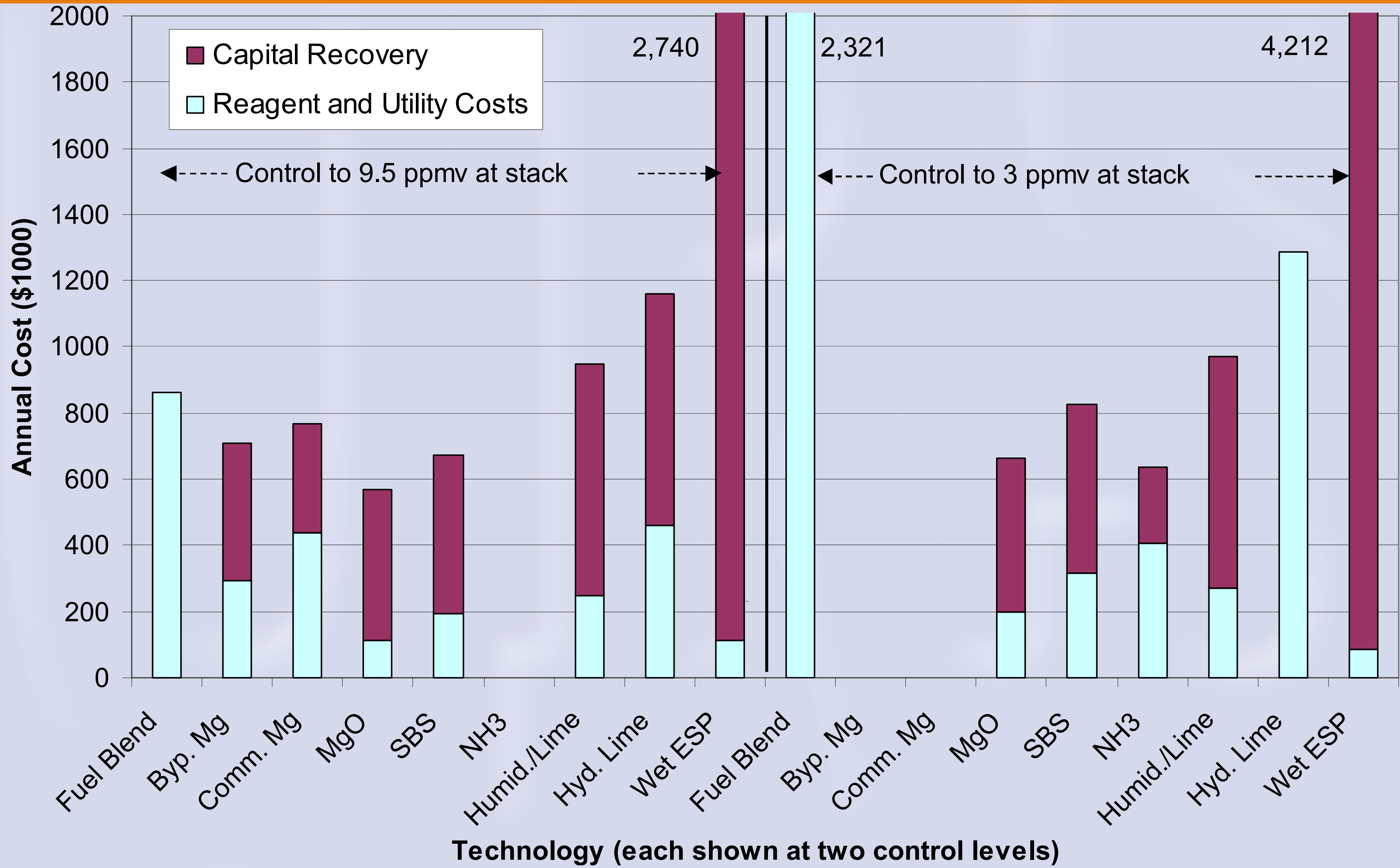
Performance Bases for Control Options

Technology	For 9.5 ppmv at Stack	For 3.0 ppmv at Stack
Fuel Blending	32% low-sulfur coal	87% low-sulfur coal
Furnace Injection Byproduct Mg	3.9:1 Mg:SO_3 ratio	-
Furnace Injection Commercial Mg	3.9:1 Mg:SO_3 ratio	-
MgO Injection Upstream of AH	1.25 mole Mg per mole SO_3 removed	1.25 mole Mg per mole SO_3 removed
SBS Injection Upstream of AH	1.0 mole Na per mole SO_3 removed	1.2 mole Na per mole SO_3 removed
NH_3 Injection Upstream of ESP	Not estimated	1.8 mole NH_3 per mole SO_3 removed
Humidification/Lime Injection Upstream of ESP	Humidification to 293^{o}F, lime injection at 1 lb/hr/kacfm	Humidification to 275^{o}F, lime injection at 1 lb/hr/kacfm
Hydrated Lime Injection Upstream of ESP	Lime injection at 2 lb/hr/kacfm	Lime injection at 5.6 lb/hr/kacfm
Wet ESP	Last field of dry ESP conversion	Wet ESP retrofit downstream of FGD

Cost Factors for Comparing SO_3 Control Technologies

Factor	Value Used
Byproduct $Mg(OH)_2$ slurry, delivered ($/dry ton of pure $Mg(OH)_2$, shipped at 18% solids, 65% purity in solids, 100-mile distance)	203
Commercial $Mg(OH)_2$ slurry, delivered ($/dry ton $Mg(OH)_2$, shipped at 58 wt% solids, 100% purity in solids, 600-mile distance)	334
Utilimag 40 MgO powder, delivered ($/dry ton MgO, 600-mile distance)	422
Sodium Sulfite, delivered ($/dry ton available Na as Na_2SO_3)	300
Ammonia, delivered from existing plant system ($/ton)	300
Hydrated Lime, delivered ($/ton)	80
Plant Low-sulfur Fuel Cost Differential ($/MM Btu)	0.20
Gypsum Byproduct Value ($/wet ton, f.o.b. plant)	5.00
Fly Ash Byproduct Value ($/ton f.o.b. plant)	3.00
Incremental Landfill Disposal Costs ($/ ton)	4.00
Annual Capital Recovery Factor	0.15

Cost Estimate Comparisons for SO_3 Control Technologies



Conclusions

- Many technologies are available to remove SO_3/sulfuric acid from coal flue gas, but:
  - More full-scale results are needed to allow utilities to evaluate performance, cost, reliability, balance of plant impacts
  - Lowest cost technology may be very site specific, require detailed evaluation to select
- Furnace $Mg(OH)_2$ injection may be cost effective at moderate control levels